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<p>This report describes the formulation, molding, testing, and delivery of new tank track pads and belts of pads to TACOM. It includes the study of hundreds of new formulations, which contained various elastomer formulations, fillers and reinforcing fibers. Prototype molds were fabricated. M60 pads and rolls of M1 pads were delivered to TACOM for road tests..</p> <p style="text-align: right;">to p. 9</p>					
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PREFACE AND ACKNOWLEDGMENTS

We wish to thank TACOM for their support of this program, and realize that it is the type of study that is usually given to a large company. We believe that we have obtained meaningful results, and that the results and this report will be helpful toward the solution of this important problem. In particular, we wish to express our appreciation to Mr. Joseph Fix, for his consideration and technical liaison, and to Mr. Phil Lawrence and Ms. D. M. Maxinoski, Procurement Department, for their aid and for granting and tolerating the no-cost extensions and delays of this program. Also, Ms. Bertha Warzybuck, DECAS, Springfield, NJ, was very helpful in aiding us through the maze of paperwork that was required for this program.

Our thanks to the personnel at Goodyear Tire and Rubber Company for their assembly of the T156 pads. We are very thankful to Goodyear in St. Marys, Ohio, for their cooperation in the assembly and delivery of the 6 by 26-shoe assembly strands of M-1 Track Pad. We could not have completed this task without their advice, consideration, and cooperation. In particular, we express our thanks to Mr. Phil McKibbons, Mr. Don E. Todd, and Mr. Jim Waesch.

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1.0. INTRODUCTION

This final report, prepared by Utility Research Co. (URC), for the U.S. Army Tank-Automotive Command (TACOM) under Contract DAAEO7-83-C-R018, describes the formulation, molding, testing, and delivery of new tank track pads and belts of pads to TACOM. Track pads are subjected to extremely severe use conditions, which can lead to early failure by a number of different mechanisms, including chunking, wear, tearing, and "blowout." This is an important problem, since a major military budget item involves replacement pads for the M60 and M1 tanks.

The work described in this report includes the study of hundreds of new formulations, which contained various elastomer formulations, fillers and reinforcing fibers. Prototype molds were fabricated, and all of the pads molded during this program were produced by use of these shortrun molds. M60 pads and rolls of M1 pads were delivered to TACOM for road tests.

2.0. OBJECTIVES

The objectives of this program were to formulate and mold new track pad materials, which would provide improved wear resistance. Another objective was to deliver M60 pads and rolls of M1 track pads for TACOM to road test.

3.0. CONCLUSIONS

Our program was successful in meeting the objectives of this program as stated above. As a result of our investigation of this important application, we have reached several conclusions.

- We were able to demonstrate that improved wear resistance pads could be developed. It would be feasible to formulate and mold a track pad that will have much greater wear resistance than current pads.
- fr. p. 1 ● It probably will not be possible to make a great improvement of the wear resistance of the current styrene butadiene rubber (SBR) compounds.
- Polyurethane elastomers that are specifically formulated for this application will be the best choice for obtaining great improvements in wear resistance in the near future.
- Even with the limited time and funds that were available to us for this program, we were successful in demonstrating the potential of our polyurethane formulations. This was accomplished in spite of the fact that much of our time was diverted to the development and fabrication of prototype molds for molding the pads that were delivered. Even if the delivered pads

are only equivalent or slightly worse in wear resistance and performance as the current pad material, this program should be considered a great success.

- The current SBR material has been developed and used for many years. We have only scratched the surface of the potential of this new material; therefore, if it performs nearly as well as the current product, there is a high probability that another moderate cost, brief program would result in a pad formulation that would provide a great improvement in performance.
- A low cost setup and rapid screening test were developed to provide a comparison of hysteresis properties of candidate compounds. This test enabled us to anticipate results that would be obtained by TACOM in their blowout tests.

Past studies and trials have shown it to be difficult to obtain polyurethane elastomers with good hysteresis properties. We were able to formulate a large number of polyurethane compounds with excellent hysteresis properties. Although many of these were too hard and did not have good tear strength, several formulations were developed with excellent overall properties including tear, abrasion, and hysteresis resistance.

One formulation (1104-32B) was molded into a Track Pad Design 142 (T142) configuration. This pad was designated T-5 and shipped to TACOM for testing. The pad went 100,000 cycles at TACOM without deterioration. When TACOM sliced the pad in half to check for visual decomposition, there was none present. The hot tear strength of this formulation was also good. The Shore A durometer hardness was slightly high at 90A. This formulation and several other candidates were not selected for the production parts due to insufficient time and funding to determine optimum mixing and molding for the production scale-up.

It was found that the molding procedures had a significant influence on the final properties for both SBR and polyurethane formulations. Both cure cycle and post cure were important in determining the final properties of the elastomer.

4.0. RECOMMENDATIONS

4.1. Pad Material

It is urgent that more investigation should be devoted to the formulation and testing of improved pad materials. We recommend that a major part of this effort should be directed towards polyurethane matrix compounds. The compounds should include short fiber reinforcements to provide resistance to tearing and chunking and hard particulate fillers to improve abrasion resistance. A further advantage of this approach will be the capability of using liquid injection molding (LIM) to produce lower cost parts.

Moreover, this type of formulation could be modified to provide resistance to chemical and biological warfare agents, and would be capable of being decontaminated.

4.2. Design Concepts

Your design department should consider designs that would provide a larger area of the pad so that the weight-per-unit area would be lowered. Also, our company has been involved in lightweight armor concepts which lead us to the opinion that replacement of the heavy steel armor plate in the M1 tank, with lightweight composite armor, would provide a great weight reduction. This would lead to improved mileage for the track pads.

4.3. Further Recommendations

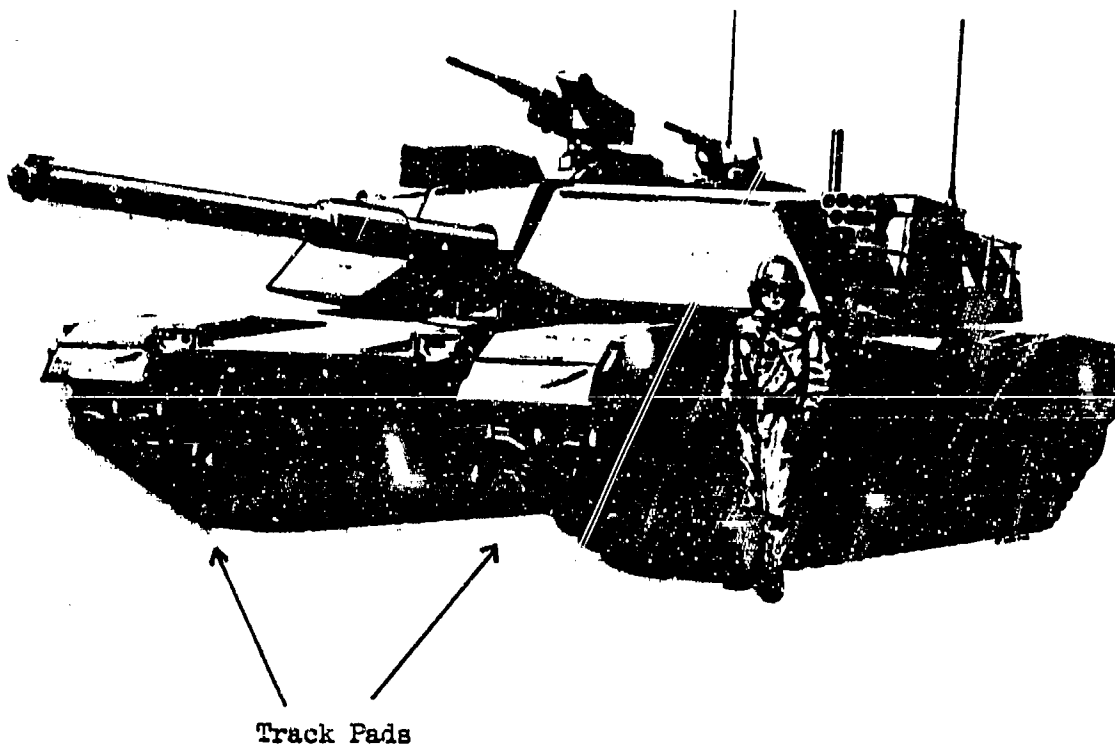
TACOM should have a number of single cavity molds for each pad design. Any company that receives a contract to improve the pad wear resistance should obtain from TACOM the proper mold to provide test parts. This would provide more time for the formulation studies, panel molding, and physical testing that are the essential tasks that could result in a great improvement of tread wear resistance.

5.0. DISCUSSION

5.1. Background

The operational life of the metal components of the M60 series tank is approximately 5,000 miles or more, while the average life of the rubber track pad that it rides on is seldom more than 2,000 miles under the best circumstances, and is usually less than 500 miles under the severest conditions.¹ This poor performance is even worse in the case of the new M1 tank track pad. A recent report by Army Materials and Mechanics Research Center (AMMRC) included this statement from the TACOM Track and Suspension R&D Symposium, 29-30 March 1982: "Current annual repair and replacement costs for track rubber used in tanks and other track vehicles are estimated to be in the range of \$100,000,000; this estimate is expected to double within the next ten years with the full implementation of the M1 main battle tank into the Army inventory." This emphasizes the importance of the objectives of this project.

5.1.1. Description of Track Pads and Performance Requirements. The M1 tank and track pads are shown in Figure 5-1. An article in the September 20, 1982 issue of the Wall Street Journal, stated that the M1 "... treads, which were supposed to go 2,000 miles, were averaging just over 1,000 miles in the tests. It may be possible that at this point in our technology, the treads cannot be made any better." A copy of this article is shown in Figure 5-2. It indicates that this is an important and difficult problem that has been well publicized. A similar article, at Figure 5-3, appeared in the January 27, 1985 issue of the Newark Star Ledger.



Track Pads

Figure 5-1. M1 Tank

Worst Enemy of the Army's New M1 Tank May Have Been Itself, U.S. Testing Shows

By AMANDA BENNETT

Staff Reporter of THE WALL STREET JOURNAL
WASHINGTON—To test its costly new M1 tank, the Army sent 41 of them on a tough, six-day field exercise. By the fifth day, only about half were working.

No one was shooting at them; they just broke down.

The tanks, which cost as much as \$2.7 million each, were designed to be the world's finest defense against enemy forces. But one of the last Army tests before the tank went into full production in late 1981 shows that the tank's own worst enemy may have been itself.

In fact, one segment of an Army test showed that the engine, transmission or other power-train gear had only a 15% probability at that time of going 4,000 miles without failing. The Army had sought a 80% chance of going that distance.

The tank is built by General Dynamics Corp., which took over production from Chrysler Corp. earlier this year after buying Chrysler defense operations.

Continued Controversy

Almost since the M1 tank first entered production, controversy has raged over the quality of the Army's first all-new tank in two decades. Evidence has made its way into the public that the tank failed to meet many principal goals during the Army's own testing. The Army has acknowledged some data supporting these views and has provided additional data refuting other such claims, but never has made its internal test

documents public.

The Army says that it has made many changes since those tests were completed last year and that the tanks currently are working well.

A copy of the results of the Army's final operational tests on the tank provides a fuller picture of the type of problems the M1 faced during Army testing. The test results were made available by the Project on Military Procurement, a nonprofit group of defense consultants and former weapons planners, which vehemently opposes the M1's production, preferring instead construction of a simpler tank.

These copies show, among other things, that during a series of operational tests, tanks were available for use for at most 54% of the time and as little as 36% of the time. The rest of the time, they were broken, being repaired or waiting for repair or maintenance.

In one set of examples, an Army agency summarizing and commenting on the operational-test results showed that one tank was down a total of 104 complete days out of 240 days.

Troubleshooting

The agency blamed in large part a troubleshooting system that frequently made wrong diagnoses, and repair procedures and equipment that it said weren't adequate. "The tank system availability" in the field "will be low unless aggressive action is taken to improve test and diagnostic equipment, manuals and troubleshooting capability."

lies," the analysis said.

"The Army says it has done just that. 'We've made a lot of improvements' since the tests were completed in the summer of 1981, an Army spokesman said. More than 150 M1 tanks are currently in operation with an Army division in Germany, the spokesman said, and "they're running very well," now that a "good, smoothly established system for repairs, parts and training" has been established. In addition, he said, "soldier acceptance is high" among tank personnel in Germany. "These are the guys that have to fight" with the tank, he added.

It would have taken a lot of fixes to satisfy some tank personnel during the operational tests. While those working with the tank were impressed with its speed and maneuverability, they complained of numerous problems that they thought impeded their safety or comfort. Some handlers inside the tank endangered crew members' eyes, evaluators believed. They complained that the .50-caliber machine gun could be fired accidentally, but that it was hard to focus precisely on target.

Neck and Back Pain

Of 29 drivers during one test, 27 reported neck and back pain bad enough to require medical attention after operating the tank for several hours with the hatch closed.

The Army nonetheless maintains that with the fixes it has made, the M1 is a superior tank. "As it sits right now on the ground, it's as good as or better than any tank that's fielded in the world," the Army spokesman said.

Still, the Army spokesman conceded that some of the problems "maybe aren't fixable." The tanks, which were supposed to go 2,000 miles, were averaging just over 1,000 miles in the tests. "It may be possible that at this point in our technology" the tanks can't be made any better.

As for the durability of the power train, the Army said it has made corrections to a number of areas such as the drive shaft and gear boxes, and has just begun a series of tests to see if that increases longevity. Using a combination of different operational and developmental tests and throwing out failures that it doesn't consider to be the tank's fault, the Army figures the tank stands a 37% chance of going the 4,000 miles without a breakdown of critical drive-train parts.

In St. Louis, a spokesman said General Dynamics wouldn't have any comment.

Figure 5-2. Wall Street Journal Article



January 27, 1983

Controversy swirls around supertank

By ROBERT LEWIS

Newhouse News Service

WASHINGTON—If war comes to Europe, U.S. military planners envision a ground attack by Warsaw Pact nations—with the Soviet Union's massive arsenal of heavy and medium tanks spearheading the assault.

While the Communist bloc holds a better than 3-to-1 advantage in armor over NATO forces, the Pentagon is counting on superior performance by the United States' new M1 Abrams tank to offset Russia's superior numbers.

According to the Pentagon, the M1 is the world's finest tank and outclasses the Soviet's T80 and West Germany's Leopard in mobility, firing accuracy and crew survivability.

But this maneuverability—a critical factor in armored combat—came at high cost and raised debate over whether the M1 can live up to expectations. The Army insists the M1 can, but this probably won't be known with any certainty unless and until the tank actually performs in combat.

Because of the tank's complexity, however, the military was forced to make technical tradeoffs, including:

- Higher fuel consumption to gain mobility. This reduces the tank's range and could cause logistical problems during combat.

Poor mileage also limits the M1's range. At 4 gallons per mile, the M1 could travel only 125 miles on its 500-gallon fuel tank. The Army lists the M1's range as 275 miles.

Another major problem with the M1 has been its tracks, which average 850 miles of use before replacements are needed. The Army had expected a track life of at least 2,000 miles.

A Pentagon spokesman says the Army is soliciting proposals from industry for development of a more durable track. "We believe it's feasible to get 2,000 miles or even more," a Pentagon official said.

Figure 5-3. Star-Ledger Article (Newark, NJ)

This article states that, "Another major problem with the M1 has been its tracks, which average 850 miles of use before replacements are needed. The Army had expected a track life of at least 2,000 miles."

The M60 is in a weightclass near 57 tons and travels about 25 miles per hour over rough terrain. The pad is subject to extreme stress and high energy buildup. For the M1 tank, which is closer to the 63 ton weightclass and travels at up to 45 miles per hour over rough terrain, the stress and energy buildup is even greater. In either case, the effect is one of a demanding wear condition. An important factor in the potential damage to the track pad material is the deformation of the elastomer when under load and then a quick return to its original configuration. The quick repetition of this action can produce extremely high temperature/energy increases so that the material will be subject to thermal degradation in combination with the physical forces causing wear. In addition, incursive road objects tend to produce highly localized tearing and puncturing forces that can quickly damage the tank track pad.

5.1.2. Discussion of Track Pad Material. The current material that is used to manufacture tank track pads is SBR rubber. Our plan for this program was to investigate improvements of SBR compounds by applying our background in the use of fillers and reinforcements. We also planned a parallel effort to investigate polyurethane matrix composites that may provide improved wear resistance, and also have other properties that are required for this application. Polyurethanes have been noted for excellent abrasion and wear resistance. However, prior attempts to use this type of material for automotive tires or tank track pads have led to failures due to reasons other than wear resistance. One main reason has been the hysteresis heat buildup that occurs during the rapid temperature rise in the center of the pad to over 300°F, and many polyurethane formulations and even some conventional SBR rubber formulations fail by blowout due to rapid thermal degradation. Because of this fact, a main test that is conducted at TACOM is the blowout test, in which a pad of the test material is placed on a test fixture and subjected to rapid compression cycles. Any material that survives 100,000 cycles without blowing out is considered a good candidate for this application.

5.1.3. Polyurethanes for Track Pad Application. Although early attempts to develop a polyurethane automobile tire had failed, there has been a resurgence of activity in this field. A paper that was presented at the Fall, 1983 meeting of the Polyurethane Manufacturers Association stated that, "Our testing, confirmed by independent evaluators, convinces us that the molded (polyurethane) tire is capable of penetration into all tire market segments with a product offering superior performance at a price competitive with existing technology."² A lower heat buildup than the comparison conventional radial tire was reported, along with reduced tire tread loss, and superior cut-growth resistance. A 50 percent longer life was forecast. A paper presented at the May, 1984 meeting of the Rubber Division, American Chemical Society in Indianapolis, Indiana reported the study of polyurethane tires for Israeli army vehicles. These tires had conventional treads with a LIM polyurethane carcass.

The later reports verify the fact that polyurethanes are worth investigating as a potential means for developing wear resistant tank track pads. All of the prior investigations of polyurethane tires have apparently involved the unfilled polymer. In the early stages of this program, the main effort involved screening a large number of unfilled polyurethanes in order to choose the best candidate matrices for further formulations containing fillers and reinforcing fibers, while also testing the unfilled matrix for comparison.

AMMRC has taken a strong interest in the "Evaluation of Polyurethane Elastomers for Application in Vehicle Tracks." A paper with that title was presented at the 1984 Society of Plastic Engineers Annual Technical Conference (ANTEC). The authors were Anthony L. Alesi, William W. Houghton, Margaret E. Roylance, and Robert W. Simoneau. This was an excellent paper that gave a good insight into the potential benefits and disadvantages of using polyurethane elastomers for vehicle tracks. The following excerpt is from that paper.

Pad durability is a matter of concern since track replacement is most often necessary because of pad wear. Pads can be worn through to the metal in a few hundred miles of off-the-road travel at high vehicle speeds and track replacements is costly. Per mile costs can be multiples of the fuel cost. The nature of the ground surface, the speed, weight, and weight distribution of the vehicle and ambient weather conditions are some of the factors that influence pad wear.

Track pads are subject to cyclic compressive loading against ground surfaces that can be highly irregular and may contain loose objects such as stones. Local strains can be very high. Vehicle travel involves linear and rotary rubbing motion of the pad against the ground. Friction, cyclic loading and the resulting hysteresis raise pad temperature. The environment--sunlight, water, oxygen, ozone, air and ground temperatures--also interacts with the rubber. Causes and mechanisms of wear are being investigated and chemical thermal and mechanical factors identified. Wear can occur through abrasion, fatigue and "chunking." Chunking is the loss of large pieces of elastomer and is the most rapid of the wear phenomena. Catastrophic failure can occur either as "blow-out" caused by hysteretic heating or by debonding from the metal supporting structure.

Synthetic rubber is now specified for use on U.S. tracked combat vehicles and only styrene-butadiene rubber (SBR) compounds have actually been purchased. As a result most military research and development seeking to increase track pad durability is concerned with synthetic and natural rubber, but polyurethanes and other elastomers are also being investigated. Polyurethanes offer some attractive properties, compared to rubber, such as higher strength and excellent abrasion resistance. Disadvantages cited are higher hysteresis, lower friction and susceptibility to hydrolysis.

This paper describes some of the work being conducted at the Army Materials and Mechanics Research Center with castable urethane elastomers. Hysteretic heating was used as a criterion for selection of candidate polyurethanes for several reasons. There is a possibility of catastrophic blow-out from excessive hysteretic heating, but more importantly, such heating will raise the pad temperature and change the elastomer's response to its loading and environment. Also, elastomer degradation will occur from continued and repeated operation at elevated temperatures.

Many interesting papers related to track pad elastomers were presented at the Thirty-Second Sagamore Army Materials Research Conference, June, 1985.

We are pleased to observe the increased activity, especially by AMMRC, on research involving the polyurethane elastomers. We believe that these elastomers have the best potential for providing an early solution to the problem of significantly increasing the wear resistance of track pads. However, we believe that the judicious use of fillers and reinforcements will be essential for the greatly improved performance that should be feasible with a polyurethane elastomer composite. Prior reports, including those cited above, have not indicated any detailed investigation of combinations of fillers and short fiber reinforcements in polyurethane.

5.1.4. Fibers for Track Pads. There are many potential benefits in the use of short fibers for the reinforcement of rubbers and elastomers. A typical study showed that the use of wood cellulose fibers more than doubled the burst strength of extruded rubber hose.³ Another study of natural cellulose fibers, which had an aspect ratio of 100:1, reported that, "... experimental tires with 10% fiber in the bead filler typically ran for 65,000 km without failure."⁴ However, in our studies, very high loadings of fibers had an adverse effect on the hysteresis problem, and can lead to processing problems, so the type, loading, and orientation of fibers in a track pad must be investigated and carefully controlled.

5.1.5. Fillers for Track Pads. There are also many potential benefits in the use of fillers in plastics and elastomers.⁵ In the case of the track pad application, the proper choice of fillers can increase the thermal conductivity of the elastomer, which can spread the localized hysteresis heat and prevent blowout of the pad. Also, the addition of hard fillers to the formulation can provide improved abrasion resistance. Excess loading of the fillers would be detrimental for many reasons, including the fact that the resultant very high durometer is not desirable for a track pad. Therefore, the filler type must be carefully chosen and the content of fillers must be optimized.

5.1.6. Contract Requirements. Our scope of work, as stated in the contract, was to provide the necessary personnel, services, material, and facilities to accomplish the following:

Conduct research in compounding to generate a track pad or track elastomer superior to those existing under the current MIL-T-11891. The contractor shall be exempt from the provision of MIL-T-11891, and any other specification. The contractor shall be completely unrestricted in the quest to improve track pad elastomers. The tracks, which shall be used for sample preparation, are the Track Pad Design 142 (T142) and the Track Pad Design 156 (T156) track pads. The contractor shall use his own knowledge and experience to formulate a more durable and longer lasting track pad. The contractor may generate more than one formulation for the evaluation.

The contract shall be conducted in two phases, Army designations CLIN 0001 and CLIN 0002. CLIN 0001 is for the formulation of compounds and lab testing of those compounds to determine their properties. The contractor shall also generate lab samples of the compounds and shoe bodies for blowout and other tests to be conducted by the contractor and the Government. CLIN 0001 is necessary to select satisfactory compounds. The contract may be completed at the end of CLIN 0001, if the Government determines satisfactory results will not be achieved. CLIN 0002 will consist of the fabrication of T142 track pads and track shoes for M1 field tests. CLIN 0002 shall not be initiated without the written approval of the Contracting Officer.

CLIN 0001 consists of the formulation of improved compounds and the performance of contractor lab tests verified by TACOM. The contractor shall supply ten of each sample in the form of shoe blocks to TACOM for lab tests of any compounds considered for fabrication in CLIN 0002. The contractor shall be uninhibited in the pursuit of superior track elastomers.

TACOM testing of compound samples and shoe blocks produced under CLIN 0001 will include blowout on the Baldwin Fatigue Testing machine, crack propagation as determined by the "J" factor, heating generation and crack initiation and other tests determined necessary by the Government.

CLIN 0002 shall provide hardware for vehicle testing. If CLIN 0001 work has been successfully accomplished and written approval is received from the Contracting Officer to proceed with CLIN 0002, the contractor shall provide the following for each compound fabricated into track components for field tests:

- | | |
|----------------------------------|-------------------------------------|
| • 2 sets Abrams T-156 track (M1) | 6 rolls consisting of 26 shoes each |
| • T-142 pads (M60) | 50 each |

5.2. Material Selection and Formulation

5.2.1. Preliminary Studies. We reviewed the literature and our own experience related to conventional rubbers and urethane elastomers that might be used for the matrix of the composites that we planned to formulate. A literature search by PLASTEC was conducted (see Appendix A). Although some pertinent articles were located, no literature reference was helpful for guidance towards formulations that could have improved wear resistance.

Many manufacturers of formulation ingredients, such as DuPont Company, Uniroyal Corporation, Upjohn Company, and Rubicon Corporation, were contacted and technical details were discussed.

5.2.2. SBR Compounds. SBR has been the standard material for track pads. It has also been used for commercial automobile and truck tires. There are many recorded and proprietary formulations for SBR, and slight variations of the formulation can have a dramatic effect on the performance for a specific use. We had proposed to study standard and new formulations of SBR. Our plan was to use our background in the optimum application of fillers and reinforcements, in order to improve the performance of this rubber. One of the main failure modes of tank track pad is blowout. This is caused by the rapid compression cycles that the pad undergoes, which results in the rapid buildup of heat in the center of the pad. Since the rubber has poor thermal conductivity, the internal heat buildup, which can reach over 400°F, causes the rubber to decompose into gaseous products that expand and can blowout a large section of the pad. One of our early plans was the use of high levels of fillers and reinforcements, which have much higher thermal conductivity than the rubber, in order to obtain rapid dissipation of the heat buildup, including conduction to the adjacent metal components, so that the blowout could not occur. Therefore, early in this program, much of our studies involved the use of high loadings of fillers and short fiber reinforcements in SBR.

5.2.3. Polyurethane Compounds. In section 5.1. we discussed the advantages and prior failures of polyurethane tires and track pads. Early work in this program convinced us that the polyurethane-based elastomer offered a greater potential for major advances in tread wear resistance than the SBR compounds. Therefore, most of the later developments in CLIN 0001 involved polyurethane formulations, moldings, and tests. Some of this work is discussed below.

The screening of candidate materials started with about 70 different elastomers or composite systems containing filler and/or reinforcements that were molded as small trial panels about 4 in. square and 0.080 in. thick.

We then continued our formulation studies by molding over 300 different elastomer and composite systems in a variety of combinations of formulation ingredients, fillers, and reinforcements.

We performed qualitative and semi-quantitative testing of the matrix material for optimum properties of tear strength, abrasion resistance, durometer hardness, resilience, molding characteristics, and bondability to steel. After the matrix was tested, the fillers and reinforcements were added to our formulations and again tested for the same properties to find the best materials.

Various urethane matrices were tried, commercial as well as our own. Different fillers and filler loadings were used to optimize abrasion resistance and hysteresis. After determination of suitable filler loadings, work continued with short fiber additions to the best formulations.

We believed that the fibers would improve tear strength while conducting heat away from the center of the pad, thereby improving hysteresis. While the fibers greatly increased tear strength, high loadings had a detrimental effect on hysteresis.

5.2.4. Procedures Used. The following figures will indicate the procedures that were used in this program. Initially, we molded hundreds of test panels by use of the many different polymer components, fillers and short length reinforcements. Fiber types included glass, Kevlar, carbon-graphite, metallic, nylon, and polyester. Fillers included silicon carbide, aluminum oxide, and microspheres of various types. Some of these test panels are shown in Figure 5-4. The panels were used to determine many properties, including tear strength, abrasion resistance, high temperature (300°F) resistance, and resistance to hydrolysis for extended periods in high humidity. Initial indications of moldability were also obtained by molding test panels. Hundreds of these panels were molded during the first two months of this program.

On the basis of the results of panel tests, three basic formulations were selected for further investigation. These were molded into test pyramids as well as panels. The pyramids measured approximately 7/8 in. by 7/8 in. at the base, 1/2 in. by 1/2 in. at the top, and 7/8 in. high. Figures 5-5 and 5-6 show part of the hundreds of pyramids, including many different modifications of the best formulations, that were molded. The pyramids were used to screen the test materials for resistance to hysteresis heat buildup, or resistance to blowout. Since commercial flexometers cost in excess of \$20,000, we did not consider that this expenditure could be justified for this program. Also, there are companies that will perform flexometer tests, but the cost per test is relatively high and we required hundreds of tests, which could lead to time delays in our program. Therefore, the ingenuity of our rapid impact test, by use of a simple air impact hammer, proved very useful and informative as a guide to our choice of best formulations for this application. Figure 5-7 is a sketch of the rapid impact test setup that we used to screen materials, as our rough equivalent to the TACOM blowout test.

Figure 5-8 shows some of the molds and mold components that we fabricated for this program. All of these were derived from T142 and T156 pads that were loaned to us by either TACOM or Goodyear Tire and Rubber Company.



Figure 5-4. Molded Elastomer Test Panels

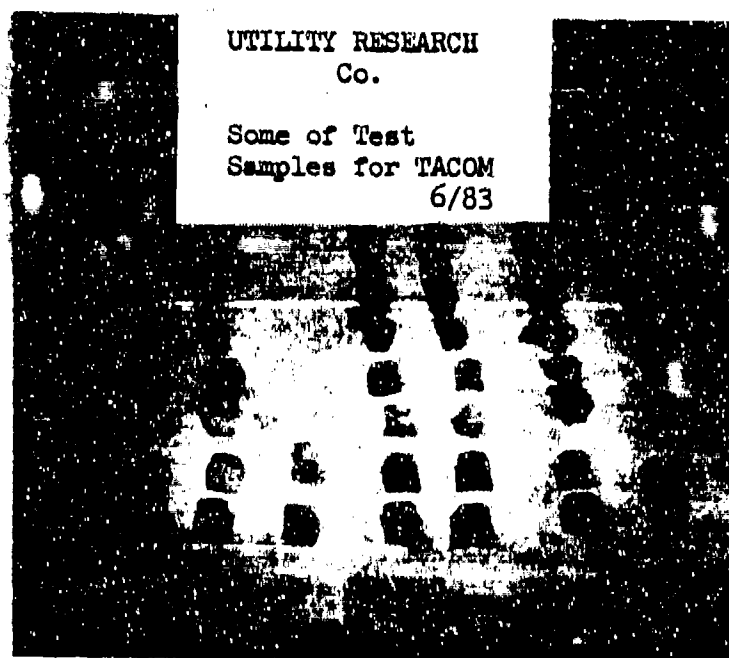


Figure 5-5. Molded Test Pyramids

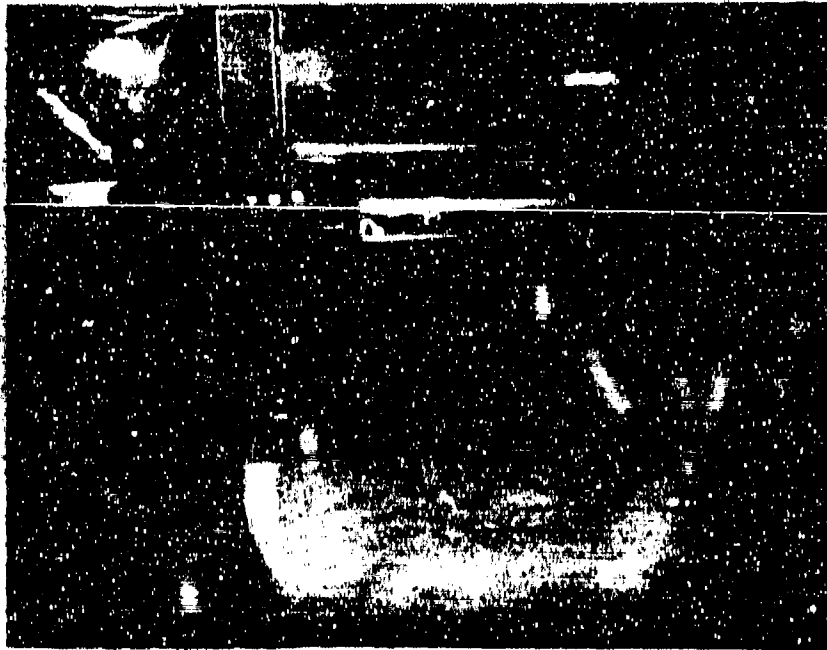


Figure 5-6. Test Pyramids on File Boards

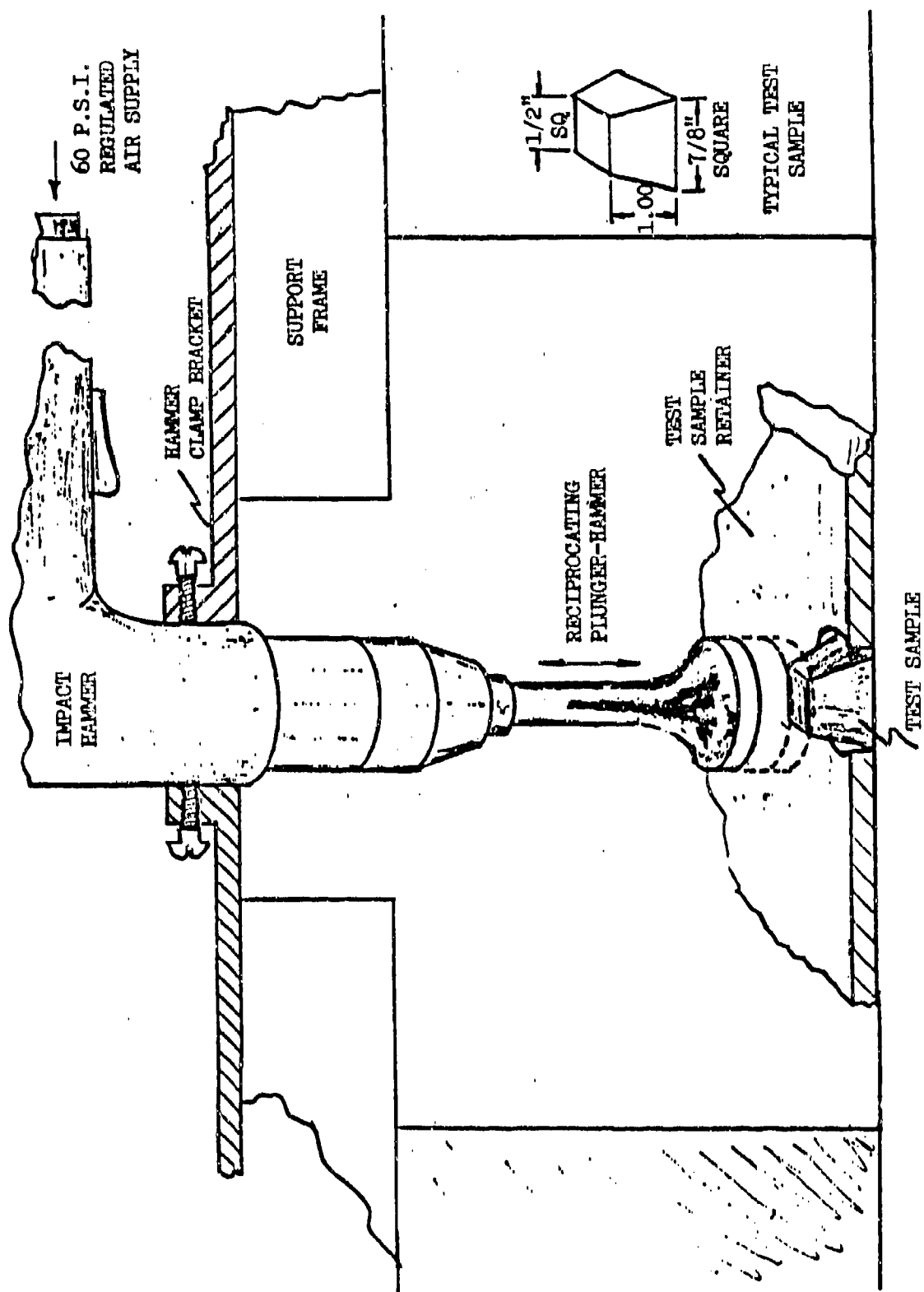


Figure 5-7. Sketch of Rapid Impact Test

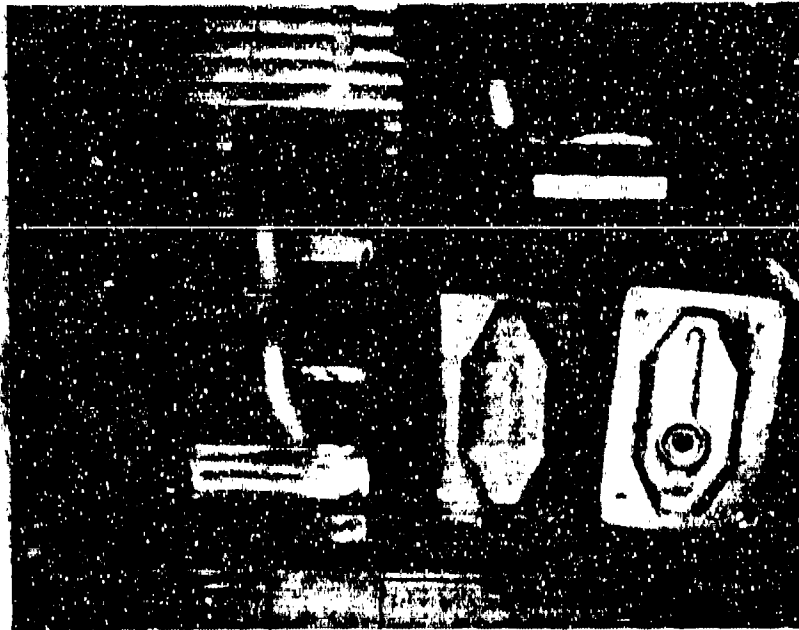


Figure 5-8. Molds and Mold Components

Our initial prototype molds were constructed with aluminum-filled epoxy composite. Later molds were made with cast aluminum. In the right foreground are the aluminum molds of the T142 pad, and a molded pad in the lower half of the mold is shown in the right background. On the left and left background are shown plaster models of the T156 pad, and an aluminum mold for the T156 pad is shown in the center of the photo.

Figure 5-9 shows the T142 mold being placed into the molding press between the preheated metal platens. Each formulation required a different cycle of cure temperature, time, and pressure.

Figure 5-10 shows the T156 mold in a compression molding press during the molding cycle. Figure 5-11 shows a T156 molded pad, prior to removal from the bottom half of the mold, and Figure 5-12 shows the molded pad after removal from the prototype mold and edge trimmed.

Figure 5-13 shows two pads that were returned to us by TACOM after they had been tested in the TACOM blowout test. These were early moldings of our new formulations, and we were pleased that both the T142 pad and the T156 pad passed the maximum 100,000 cycles of the test without any signs of failure. One of the T142 pads that had been subject to this test was cut through for examination, and the cross section indicated that there had been no change in the visual appearance of the material. Many similar materials, with excellent physical properties, are often severely damaged during this test.

Figures 5-14 and 5-15 are photos of T156 (M1) track shoe assemblies, which were delivered at the end of this program to Aberdeen Proving Ground for road tests. The pads were molded at our laboratory, and were assembled into belts at the Goodyear Tire and Rubber Company, St. Marys, Ohio.

5.3. Mold Development and Fabrication

A great deal of our time was spent in the development and fabrication of the prototype molds that were used to mold all of the pads that were made during this program. We had hoped that a compression mold, or, preferably transfer or LIM tooling, would be available to us from TACOM even though this had not been promised as part of our contract. At one point in this program, we received word that a LIM mold might be available to us for the T156 pads, but our request for this tooling was rejected.

All of the molds were derived from models of a T142 pad, supplied by TACOM, and two T156 pads that were loaned to us by Goodyear. These model pads were used to fabricate split shell molds of silicone rubber with plaster shells. The models were first coated with thin sheets of wax, in order to take into account calculated shrinkage factors for the final molded pads. Split half secondary models were then cast into the silicone molds. These plaster models were used to prepare initially aluminum-filled epoxy molds and later cast aluminum molds. Some of these components are shown in Figure 5-8. We were pleased with the quality and quantity of pads that we were able to produce from these relatively low cost molds. We were



Figure 5-9. T142 Mold Removal From Press



Figure 5-10. T156 Press Molding



Figure 5-11. T152 Removal From Mold

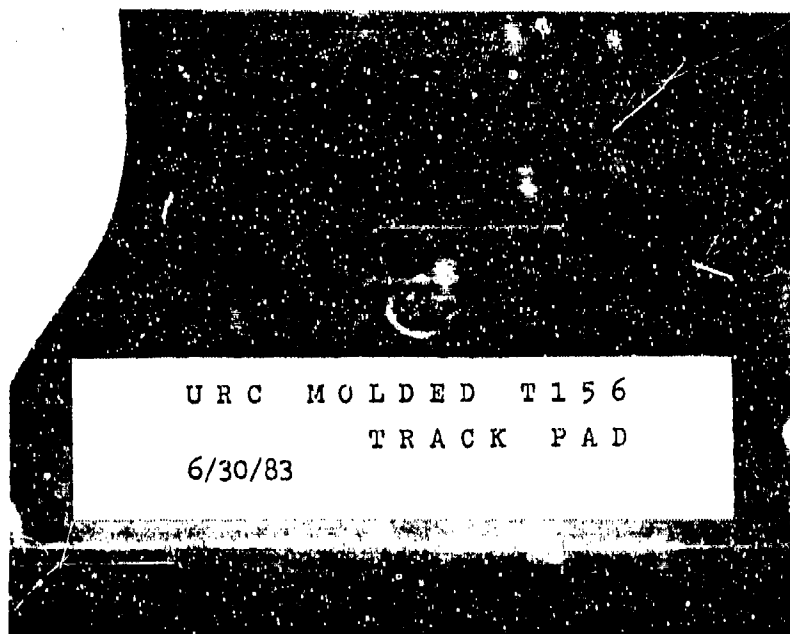


Figure 5-12. URC Molded T156 Track Pad

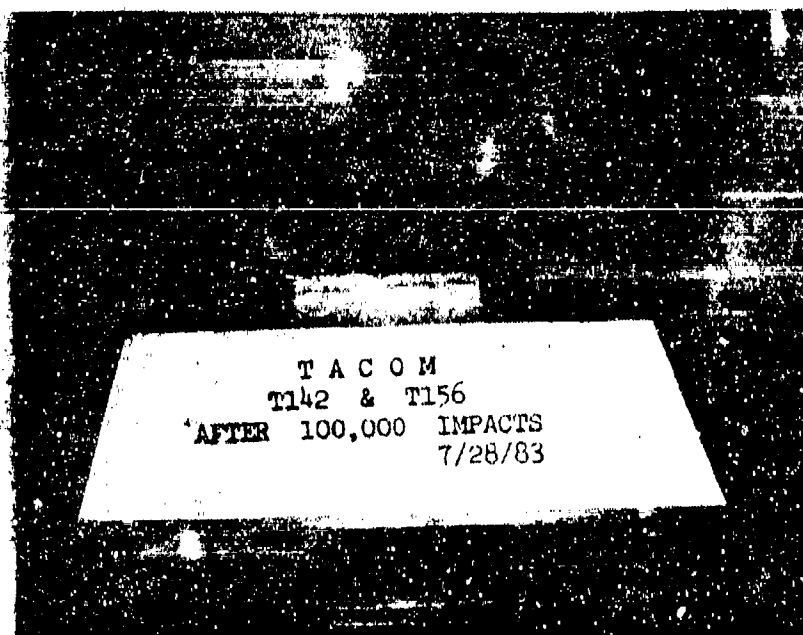


Figure 5-13. URC T142 and T156 Pads After Test by TACOM

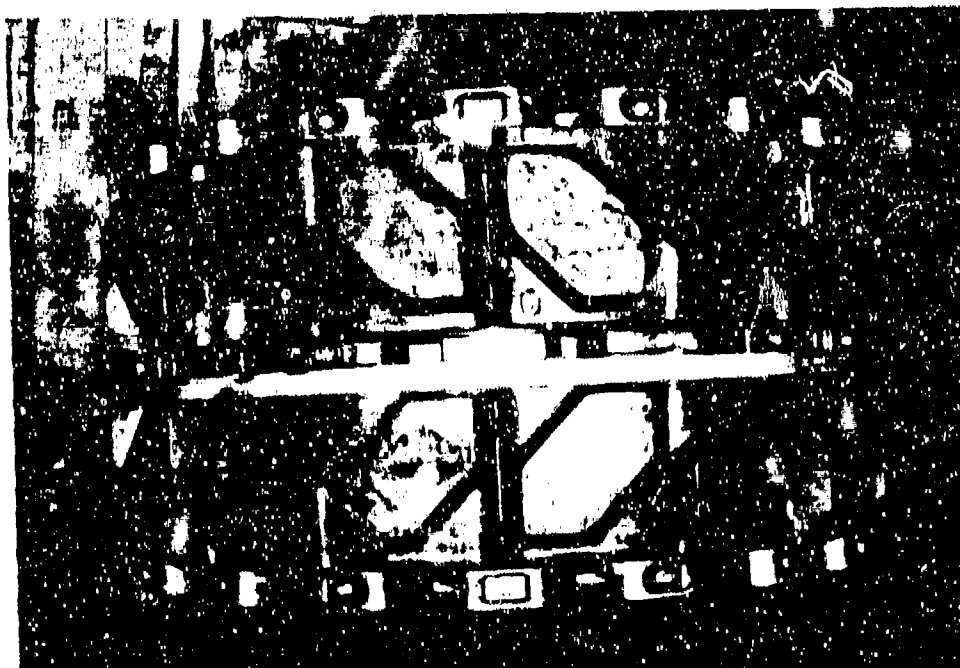


Figure 5-14. T156 Track Shoe Assembly View A



Figure 5-15. T156 Track Shoe Assembly View B

concerned that the tolerance of the T156 pads might cause a problem of their assembly onto the rolls, but this was not the case and further justified our use of the low cost tooling.

5.4. Track Pad Molding

Over 600 pads were produced during this program. All of these were molded in our prototype molds, by a compression molding process. In the case of our SBR compounds, the milled sheets were placed into the mold and then cured by the usual heat and pressure cycle. In the case of our formulated urethane composites, the liquid system was poured into both halves of a mold. Since the liquid was quite viscous, one-half of the mold could be placed quickly onto the second half and then the assembly was placed onto the press for curing. This process is illustrated in Figures 5-9, 5-10, and 5-11. If time had permitted, we would have preferred to set up the polyurethane composite molding as a LIM process. This would have meant lower cost per part and faster molding, but would have taken much time for tooling and developing a modified molding procedure.

5.5. Pad Elastomer-to-Metal Bonding

The designs of the T142 and T156 pads require that the elastomer bond well to the adjacent metal. Therefore, we investigated the bonding of the best candidate elastomers to both the T142 metal plate and the T156 metal binocular. Various bonding agents and primers were studied. We were successful in developing satisfactory bonding materials and procedures.

The selected bonding agent was applied to the surface of the metal by either brush or spray, prior to the usual molding cycle.

5.6. Testing

The only really meaningful tests for the T156 and T142 pads are the road tests that will determine the durability and wear rates under various terrain that simulate actual use. However, it would be expensive, and there would be great time lapses in trying to schedule a road test for each series of trial pads. Therefore, it is very important to perform rough screening tests, and simulated environmental tests combined with physical testing in order to select the best candidate materials for molding the pads that will be used for the final road tests.

5.6.1. General. We have had a membership in the American Society for Testing Materials (ASTM) for many years, and have a good knowledge of standard test procedures. However, we have usually found it advantageous to use rapid screening tests that do not conform exactly to an ASTM or other standard procedures. Therefore, most of the early tests that were performed during the CLIN 0001 program were modified ASTM tests, which were run in order to determine the relative merit rating for a series of related formulations.

The tests that were run included tear strength, durometer hardness, blow-out test, and relative abrasion resistance. With regard to the latter test, our early abrasion screening test indicated that some of our trial compounds had six to ten times the abrasion resistance of the standard SER tank tread material which was obtained from the TACOM lab. Similarly, in evaluating tear strength, our trial compounds were found to have two to four times the tear strength of the standard SER tank tread. This was encouraging because the improved abrasion resistance should correspond to improve wear properties of the track pad. In addition, improved tear strength should help to prevent the cutting and chunking which occurs in cross-country tests. We incorporated thermally conductive fillers to help dissipate the heat generated in the track pad rubber at high speeds on hard pavement.

5.6.2. Tear Strength Tests. ASTM D 524 specifies tear strength tests by use of different dies for cutting the test specimen. Many of our tests were made by use of Die B or Die C. However, most of our tear tests were performed by use of a simple "trouser tear" test, similar to the test described in ASTM D 1938. These tests were usually run at room temperature, but many tests were made with samples exposed to 300°F for up to 4 hours and after exposure to high humidity at about 220°F for several days.

5.6.3. Blowout and Hysteresis Tests. One of the primary modes of failure of current tank track pads is blowout, which results from excessive heat buildup within the elastomer. This causes rapidly formed decomposition gaseous and liquid products that can blow out chunks of elastomer from the pad surface. The heat buildup is due to the rapid compression cycle of the pad. This problem has been a concern with the M60 track pads. The M1 tank is heavier and travels faster than the M60, so the heat buildup or hysteresis problem is potentially even more severe for the M1 than the M60.

We considered it essential to our program that we could screen the hundreds of formulation candidates for their relative resistance to blowout. This type of data, which would indicate the effect of rapid compression cycles on a rubber sample, can also be obtained by use of a Goodrich or Firestone Flexometer, as described in ASTM D 623. This type of test equipment can be used to compare the fatigue characteristics and rate of heat generation of different rubber vulcanizates when subjected to dynamic compressive strains. However, it would not be feasible, with the limited time and funds of this program, to set up a commercial flexometer or a test fixture and equipment equivalent to that of TACOM's. Therefore, we designed our own method for rapid screening of the relative rating of hundreds of formulations for resistance to blowout.

Figure 5-7 is a sketch of our Rapid Impact Tester, which contains an air hammer, Chicago Pneumatic Model CP715, which is rated at 1,900 impacts/minute at 90 PSIG.

In order to obtain meaningful results in this test, the geometry of the sample and impact hammer must be held constant for each test. This

includes the sample size, and the distance between the top of the pyramid and the hammer. The air pressure must be constant. During each series of tests, a known control sample was run. Some polyurethane composites with excellent physical properties would fail in less than one minute in this test. Failure modes included splitting, or the rapid release of molten resin from the sample.

The blowout test requirements at TACOM for the M1 pads are as follows:

- Acceptance criteria is an average of 52,000 cycles to blowout with no individual block below 45,000 cycles.
- Test to be conducted on TACOM Baldwin Fatigue Test Machine Model SF-10-U.
- Ambient temperature and test sample temperature shall be not less than 60°F.
- Static load of 1,900 pounds with a dynamic load of 2,300 pounds (block load--400 to 4,200 pounds) applied at 1,800 cycles per minute.

5.6.4. Abrasion Resistance Testing. There are many ASTM tests and various commercial test equipment for measuring abrasion resistance. These include ASTM D 2228, Abrasion Resistance of Rubber, PICO Abrader, which involves the use of tungsten carbide cutting knives as a means for abrasion, and ASTM D 4060, for determining the abrasion resistance of coatings by use of the Taber abraser. However, we set up a relatively simple device in our lab in order to determine the relative abrasion resistance of the many compounds that we molded into sheets. The device permitted us to apply a controlled pressure upon the test sheet while the sheet was subjected to an abrasive wheel.

We used various hard fillers, such as silicon carbide, in our formulations in order to improve the abrasion resistance of our track pad formulations. As a control material, we used SBR rubber sheets from a conventional T142 pad that had been furnished to us by TACOM. The abrasion resistance or wear rates of our urethane composites was far superior to that of the SBR control material.

5.6.5. Hydrolytic Stability Testing. A major concern in the use of polyurethane elastomers is their resistance to hydrolysis. Many polyurethanes, which have good physical properties, can exhibit a severe degradation of properties after even short-term exposure to humid conditions. Our prior experience with these polymers has established a known approach for obtaining good resistance to hydrolysis, but it is necessary to run tests to verify this property.

A simple long-term test that was conducted routinely during our investigation of polyurethane composites made use of a kitchen crock pot. Water was placed in this utensil, and set at a low or medium setting so that the

temperature was maintained at about 220°F and a steam environment occurred at the top of the pot. A nylon mesh was suspended over the water surface, and the test sheets and pyramids were placed on the mesh. Times varied to up to 3 weeks of continuous exposure.

5.6.6. Panel Molding and Testing. Panels were molded in simple three-plate compression molds. The usual molded size was about 6 in. by 6 in. by 0.080-in. thick. Samples were then cut from these panels or sheets in order to perform the various tests, including tear strength and abrasion resistance.

5.6.7. Pyramid Molding and Testing. The pyramids were molded in cast aluminum compression molds. The size of the molded pyramid was 7/8 in. by 7/8 in. base, 1/2 in. by 1/2 in. top, and 1 in. in height. These were used in order to test the relative blowout resistance of various formulations.

5.6.8. Adhesive Bonding Tests. The need for a good elastomer-to-metal bond was discussed in Section 5.5. above. Testing included peel tests at room temperature and 300°F, and resistance to hydrolysis after long-term exposure in hot water. Epoxy adhesives and polyurethane primers were included in those studies.

5.6.9. Formulation, Molding and Testing of Initial T142 (M60) Track Pads. After comparing the properties of various formulations in molded sheets and pyramids, the three best formulations were selected for molding the T142 track pads. An aluminum-filled epoxy prototype mold was fabricated as discussed above, and trial T142 pads were molded. The initial pads were cut apart in order to visually examine the molded pad for internal voids or defects. Also, panels of the material were cut out of the pad to determine properties such as tear strength and abrasion resistance.

5.6.10. Formulation, Molding, and Testing of Initial T156 (M1) Track Pads. The T156 pad is more than twice the weight of the T142 pad. Also, the T142 pad is molded against an essentially flat plate, whereas the metal insert in the T156 has the shape of a binocular. Because of these differences, the formulation of the molding compound and the molding process had to be modified when we made the transition from molding the T142 pads to the larger T156 pads. The first prototype mold for the T156 pad consisted of a thin silicone rubber shell, backed with aluminum-filled epoxy. This was suitable for several initial test moldings, but the overall dimensions of the molded part were not as precise as we wanted. Therefore, the subsequent molds that we fabricated were made by use of cast aluminum. The shoulder of one of the split halves had two pyramid cavities. The plan was to use the pyramids, molded during the same cycle as the pad, as a quality control method for running a blowout test on each of the initial T156 pads that were molded. Our polyurethane composite formulations were mixed in small batches, each batch large enough for only one pad and a small quality control test sheet. The sheets were used to spot check the tear strength and hydrolytic stability of the casting.

5.6.11. Miscellaneous Tests. Among miscellaneous tests that were run throughout this program were Shore A2 Durometer tests on the various materials, and thermal conductivity tests on the best candidates versus the control SHN pad material. We also made frequent microscopic examinations of molded parts and test samples.

5.7. Results

5.7.1. CLIN 0001. CLIN 0001 was the development phase of this program. Several thousand panels and pyramids were molded from over 400 different formulations during CLIN 0001. About 50 track pads were molded. Among those shipped to TACOM were the following: In June 1983, one T142 and one T156 were sent to TACOM for testing; a T142 was sent in July; in August 1983, four T156 pads were sent to Yuma for road tests, and two pads were sent to TACOM for blowout tests. After satisfactory tests during the CLIN 0001 program, TACOM gave us a contract to proceed with CLIN 0002.

During the last month of the CLIN 0001 program, we observed that several of our recent formulations might provide much better results than the Utility Research Company (URC) formulation S-12 that had been approved for us to proceed with the CLIN 0002 pilot production run. We requested a brief extension of the CLIN 0001 program so that we could do some quick evaluations of the new formulations, but this request was denied. We were informed that any extended delay in the pilot production could prevent our formulation from being evaluated in the scheduled road tests. Therefore, we began work on the CLIN 0002 production program.

5.7.2. CLIN 0002. CLIN 0002 was the production phase of this program. After TACOM had tested the T142 and T156 pads that had been molded in CLIN 0001, they gave us the CLIN 0002 contract to produce the pads that would be required for road testing.

Additional molds were constructed for the production of the CLIN 0002 pads.

Since relatively few molds and pads had been made during the CLIN 0001 program, we considered it essential to initiate quality control and verify mixing and molding procedures that would be reproducible. Therefore, preproduction samples were prepared and tested in our lab and also submitted to TACOM to verify our production quality.

5.8. Delivery of Hardware

As noted in 5.1.6. above, our contract required us to deliver 50 T142 track pads and 6 rolls of 26 shoes each of T156 track pads.

5.8.1. Molding and Delivery of T142 Pads. Sixty-five T142 were molded during the final months of the CLIN 0002 program. Quality control tests were conducted on sheets and pyramids that were molded along with the pads. At various intervals, about 11 T142 preproduction pads were sent to TACOM for blowout tests. We shipped 50 of these pads, URC Compound S-12A, to Yuma Proving Ground in accordance with the terms of our contract and instructions from TACOM.

5.8.2. **Molding, Assembly, and Delivery of Belts of M1 Pads.** Four hundred T156 pads were molded, and quality control tests were conducted on sheets and pyramids that were molded along with the pads. Because this is a larger pad than the T142, the formulation of our molding compound had to be modified from that used in molding the T142 pad. We shipped 312 of these pads, plus 20 extra pads (URC Compound S-12B), to Goodyear for assembly into belts. We requested Goodyear to ship the completed assemblies to Aberdeen Proving Grounds, in accordance with the terms of our contract.

The above shipment completed the requirements of our contract.

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APPENDIX A

Search Done
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March 28, 1983

IN REPLY REFER TO:

Fire Control and Small Caliber
Weapon Systems Laboratory, FSL

Mr. Harry S. Katz
Utility Research Company
P.O. Box 107
Montclair, NJ 07042

Dear Harry:

We have finished the search you requested on your Purchase Order No. 30302B in Improved Tank Tread Rubber Track Pads. The search encompassed five different sources and includes the PLASTEC file, Engineering Index, DTIC, and NTIS. The print-outs are numbered from 1 to 24 as follows. Some references have been removed because of restrictions on dissemination. The search strategies are listed for your information.

I. Lockheed Dialog/NTIS File

1. Track Pad
2. Track Vehicle
and
Rubber or Elastomer or Urethane or Polyurethane
3. Tractor
4. Tread
and
Wear

II. Lockheed Dialog/Engineering Index

5. Track Pad
6. Track Vehicle
and
Rubber or Elastomer or Urethane or Polyurethane
7. Tractor
and
Wear
8. Tread

III. DTIC-Engineering Index (Tech. Report)

9. Track Pad
or
Track Vehicle
or
Tractor

- 10. Combat Vehicle
and
Elastomers or Rubbers
- 11. Vehicle Tracks
and
Tires
and
Wear
- 12. Tanks (Combat Vehicle)
and
Rubbers or Elastomers
- 13. Tracked Vehicles
- 14. Treads

IV. DTIC-Work Unit Summaries (Form 1498)-Work in Progress

- 15. Combat Vehicles
and
Elastomers or Rubbers
- 16. Treads
- 17. Tanks (Combat Vehicles)
and
Rubbers or Elastomers
- 18. Tracked Vehicles
and
Rubbers or Elastomers
- 19. Vehicle Tracks
and
Tires
and
Wear

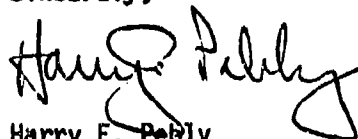
V. DTIC-Data Bank Summaries (Form 272)

- 20. Combat Vehicles
and
Elastomers or Rubbers
- 21. Treads
- 22. Tracked Vehicles
and
Rubbers and Elastomers
- 23. Tanks (Combat Vehicles)
and
Rubbers or Elastomers
- 24. Vehicle Tracks
and
Tires
and
Wear

You will undoubtedly find some duplication in these searches. If you want help in obtaining particular documents please call me and we will arrange to have someone procure them. We would try to obtain microfiches where possible, since you will have access to a reader.

We hope this information will be helpful. Our invoice for \$300 is enclosed.

Sincerely,

A handwritten signature in cursive script, appearing to read "Harry E. Peibly".

Harry E. Peibly
Chief, PLASTEC


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at address above					
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